AFCEC-CO-TY-TR-2018-0001

CONVERTING HANGAR HIGH EXPANSION FOAM SYSTEMS TO PREVENT COCKPIT DAMAGE: FULL-SCALE VALIDATION TESTS

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Contract No. N00173-15-D-2002

September 2017

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14. ABSTRACT
The fire protection systems currently installed in U.S. Air Force (USAF) aircraft hangars consist of High Expansion (Hi-Ex) foam generators located in the overhead of the space and an overhead water sprinkling system. There have been several inadvertent discharges of these systems that have resulted in significant damage to internal aircraft systems due to submersion of the aircraft in high expansion foam. The USAF has developed a technique to reduce the consequences of an inadvertent discharge by automatically controlling the maximum depth of the foam. Specifically, the inlet air to each generator would be drawn from the critical foam height above the floor using ductwork. Once the foam reaches this critical height, the foam, in theory, would then be recirculated through the generator keeping the height of the foam relatively constant. This technique was tested on an intermediate scale at Jensen Hughes headquarters in Baltimore, MD during the Spring of 2016 and needed to be validated prior to USAF hangar implementation. These full-scale tests were the final step in validating the concept and developing an understanding of the associated design parameters. The validation tests were conducted at Eglin Air Force Base during the week of May 15th, 2017.

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1. INTRODUCTION

The fire protection systems currently installed in U.S. Air Force (USAF) aircraft hangars consist of High Expansion (Hi-Ex) foam generators located in the overhead of the space and an overhead water sprinkling system [1]. There have been several inadvertent discharges of these systems that have resulted in significant damage to internal aircraft systems due to submersion of the aircraft in high expansion foam.

The USAF has developed a technique to reduce the consequences (i.e., collateral damage of aircraft electronics) of an inadvertent discharge by automatically controlling the maximum depth of the foam. Specifically, the inlet air to each generator would be drawn from the critical foam height above the floor using ductwork. Once the foam reaches this critical height, the foam, in theory, would then be recirculated through the generator keeping the height of the foam relatively constant.

This technique was tested on an intermediate scale at Jensen Hughes headquarters in Baltimore, MD during the Spring of 2016 [2] and needed to be validated prior to USAF hangar implementation. These full-scale tests were the final step in validating the concept and developing an understanding of the associated design parameters. The validation tests were conducted at Eglin Air Force Base (Duke Field) during the week of May 15th, 2017.

2. OBJECTIVE

The objectives of this test program were to validate the potential for using the proposed technique to limit the foam height in the hangar and to begin to identify the parameters needed to design a system for an actual USAF hangar installation.

3. TEST SETUP AND DESCRIPTION

3.1. General Description

Two full-scale tests were conducted during this program; one without ductwork and one with ductwork to validate the proposed concept and to verify, that the addition of the ductwork doesn’t adversely affect the system currently installed in the hangar.

The tests were conducted in Hangar 3029 at Eglin Air Force Base (Duke Airfield). The hangar was nominally 200 ft across, 100 ft deep and 40 ft high. There were five Chemguard 15000WP high expansion foam generators installed in the hangar. During the validation test, the inlet air to each generator was be drawn from a location near the perimeter of the hangar using 42 in. diameter flexible ductwork (similar to that used for clothes dryers, but much larger). A photograph of test setup is shown in Figure 1. All the contents of the hangar were removed and the walls covered with 6 mil plastic to a depth of 8 ft to minimize the exposure of the structure to the foam. The foam solution was collected and disposed of by the base environmental contractor (SWS Environmental Services Corp.) after each test.

Additional detail of the test setup and procedures is provided in the following sections.

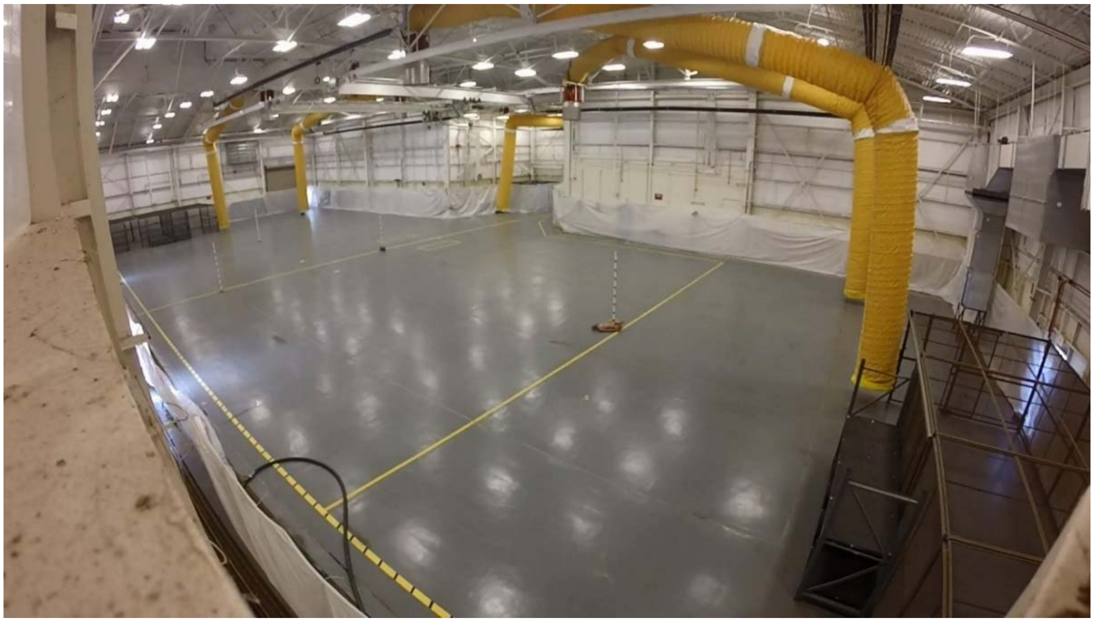


Figure 1. Validation Test Setup

3.2. Hangar

The tests were conducted in Hangar 3029 at Eglin Airforce Base (Duke Airfield). The inside of the hangar is shaped like a “T” and was nominally 200 ft. across, 100 ft. deep and 40 ft. high. A plan view of the hangar with dimensions is provided as Figure 2.

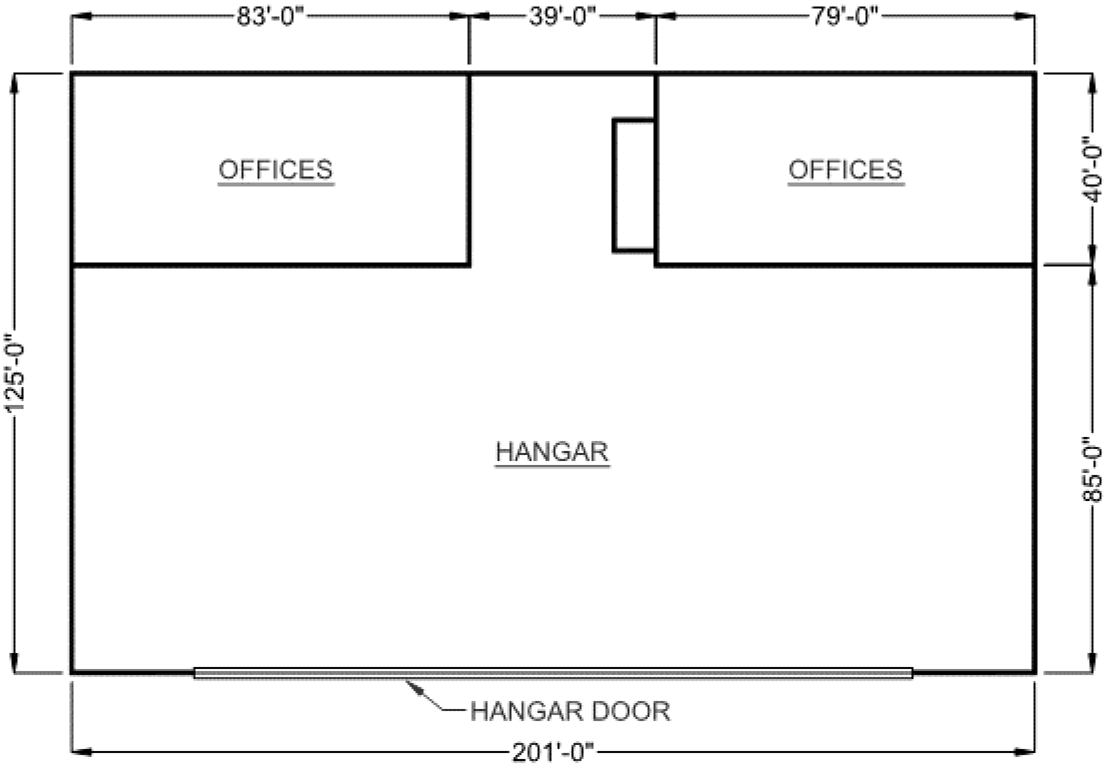


Figure 2. Hangar Dimensions (Plan View)

To minimize the exposure of the hangar boundaries (i.e., painted surfaces and the devices installed on the walls including electrical components), a poly curtain was installed around the inside perimeter of the hangar. The curtain was hung from 5/16 in. nylon rope run through a series of eyebolts installed on each boundary about 8 ft. above the floor. The curtain was made from 6 mil poly rolls, 10 ft. by 100 ft. long. The curtain was attached to the rope using nylon wire ties. A photograph showing the curtain is provided as Figure 3.

There were three metal storage cages located in the hangar, two on opposite ends of the hangar adjacent to the large aircraft door and one in the nose bay. The two cages adjacent to the aircraft door were emptied prior to the tests and were allowed to fill with foam during the test. The storage cage in the nose bay was loaded with supplies and was curtained-off during the test. The net floodable area of the hangar was on the order of 18,000 ft^2.

Figure 3. Protective Curtain on Hangar Boundaries

3.3. High Expansion Foam System

There were five Chemguard 15000WP high expansion foam generators installed in the hangar. The locations are shown in Figure 4. A photograph and schematic of a Chemguard 15000WP generator are provided in Figure 5. The discharge characteristics of the generator are shown in the plot in Figure 6.

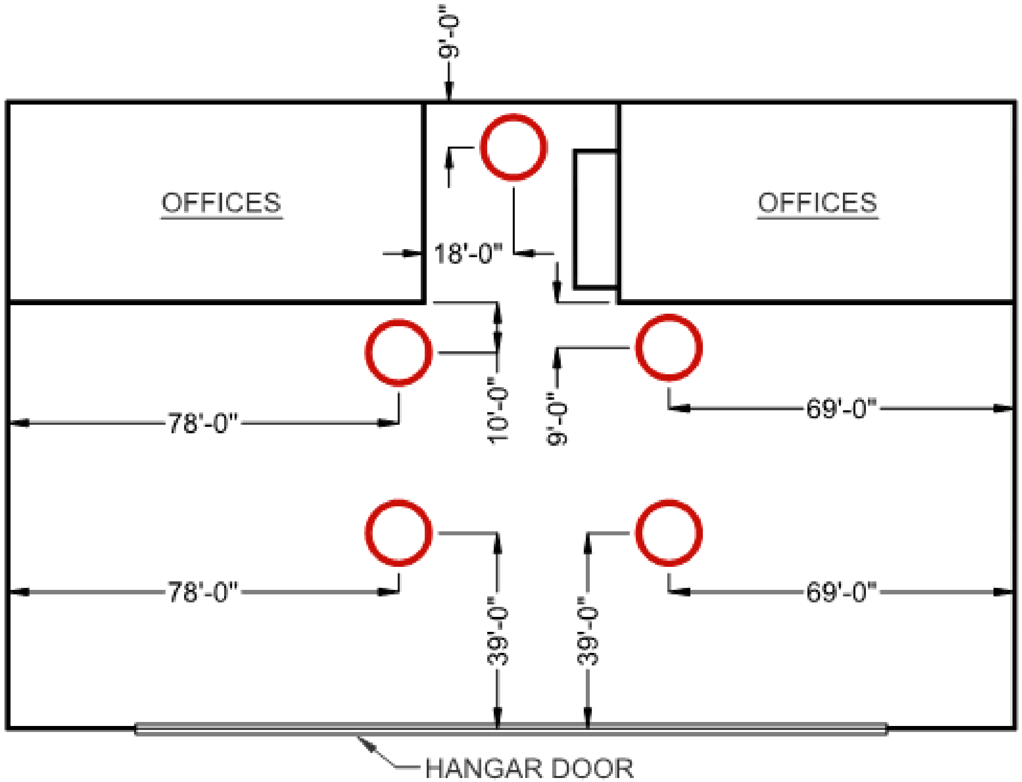


Figure 4. High Expansion Foam Generator Locations

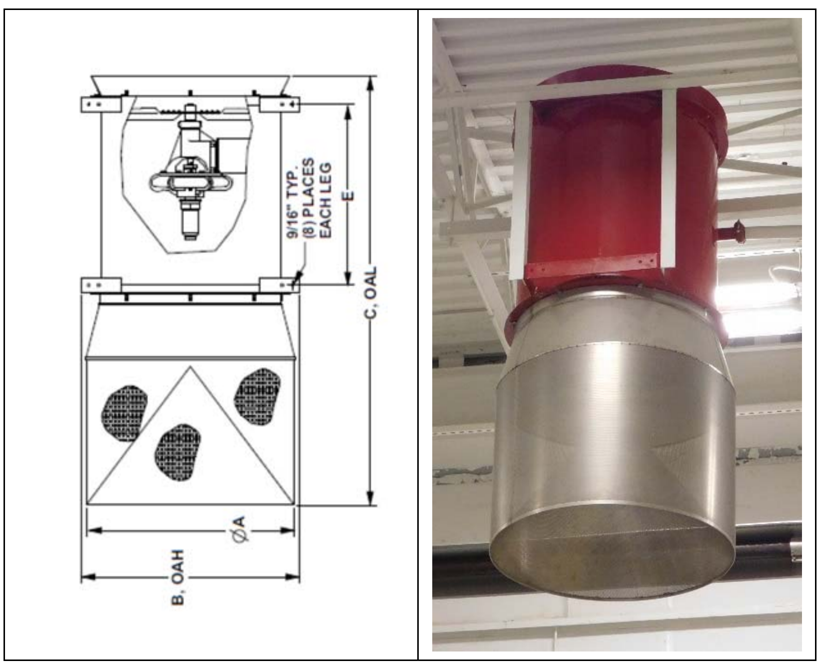


Figure 5. Chemguard 15000WP

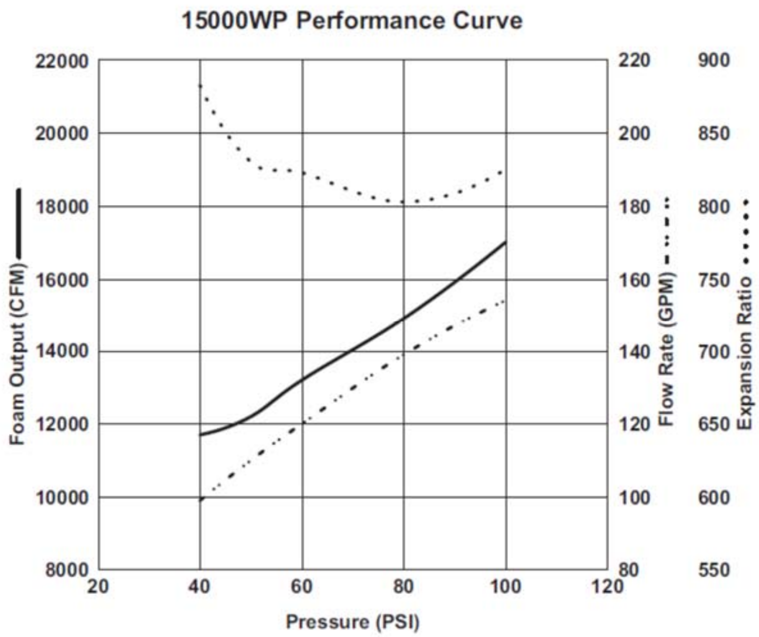


Figure 6. Chemguard 15000WP Discharge Characteristics [3]

The generators were initially installed approximately 3 ft below the overhead of the hangar (~37 ft above the floor). To provide additional space to make the connection to the ductwork, the generators were lowered approximately 3 ft during these tests. On completion of the program, the generators were raised back to their original positions. The modifications to the system were made by Hiller Systems Inc. located in Mobile, AL.

During testing, the high expansion foam system was operated from the pump room located on the south side of the hangar by Mr. Jim Devonshire. During the discharge, the generators were operated at approximately 100 psi inlet pressure. This corresponded to a flow rate of approximately 150 gpm per generator and a total system flow rate of 750 gpm. The operating pressures of the high expansion foam generators and supply system were recorded from pressure gages installed throughout the system. The system operating conditions, including foam concentrations recorded by Mr. Devonshire are provided in Appendix A.

3.4. Ductwork

During the validation test, the inlet air to each generator was drawn from a location near the perimeter of the hangar using 42 in. diameter flexible plastic ductwork manufactured by Schauenbrg, a Flexadux Corporation [4]. The ductwork was developed for, and is typically used to provide ventilation in underground mining and tunnel applications.

The duct was constructed of PVC coated nylon/polyester fabric, reinforced with an embedded steel helical spring (i.e., coil spring). The section ends included double steel rings embedded in the plastic for strength. The duct sections were connected together by zippers with built-in internal sleeves to provide an airtight connection. The duct is available in standard sizes ranging from 10 in. to 96 in. in diameter and custom lengths up to 25 ft. long (usually in 5 ft. increments).

The duct is available in two configurations; horizontal runs and vertical runs. The horizontal runs are equipped with a single set of fastening clips as shown in Figure 7. During these tests, the horizontal runs were suspended from the overhead of the hangar using ½” steel cabling run from the ceiling joist above the generator to the hangar boundary/wall.

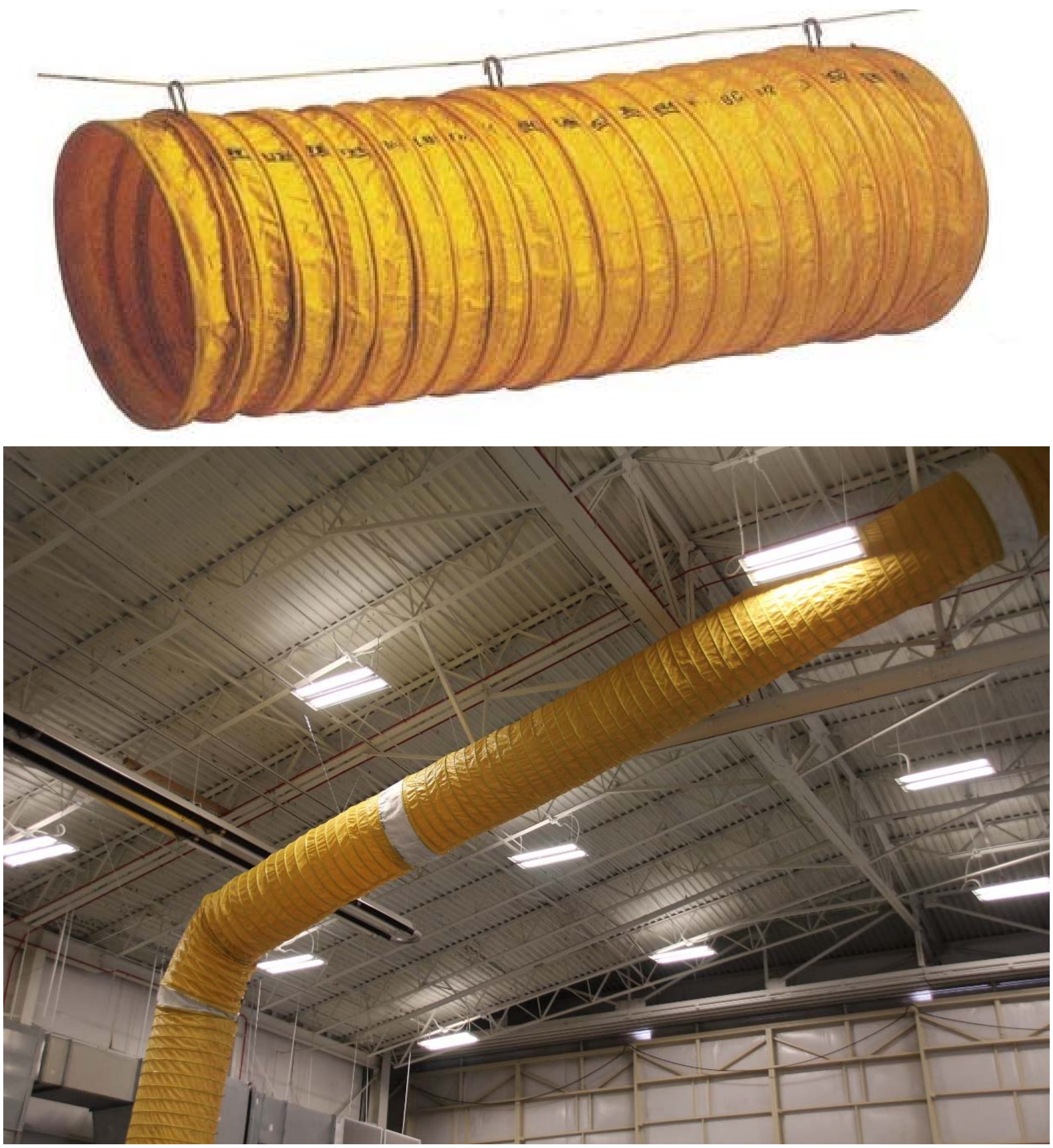


Figure 7. Horizontal Duct Configuration

The horizontal ducts were shaped into a 90-degree bend above the generator and connected to the air inlet using band-straps as shown in Figure 8.

Figure 8. Generator/Duct Connection

The vertical runs are equipped with a cable support system that runs down opposite sides of the duct as shown in Figure 9. The vertical runs were suspended from the overhead using ½" steel cable connected to the ceiling trusses. The inlets to the vertical ducts were approximately 16 in. above the floor. A typical ductwork run is shown in Figure 10.

Figure 9. Vertical Duct Configuration

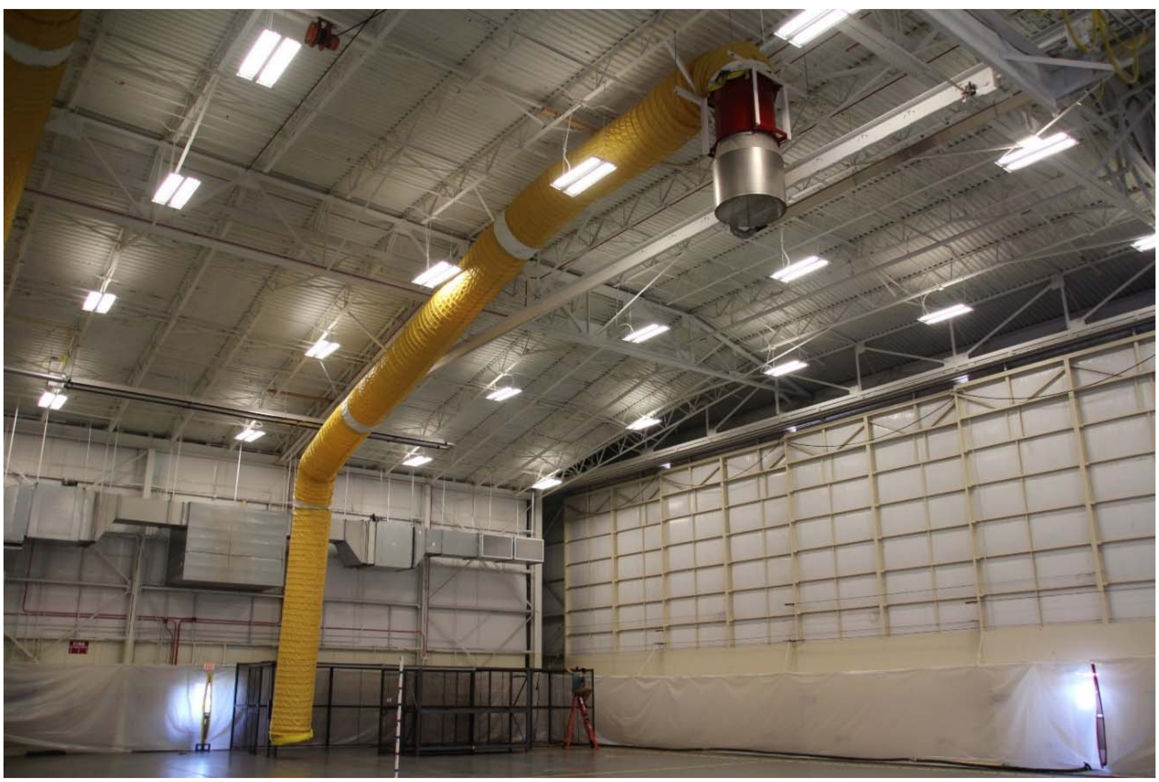


Figure 10. Typical Ductwork Arrangement

The overall ductwork configuration within the hangar is shown in Figure 11.

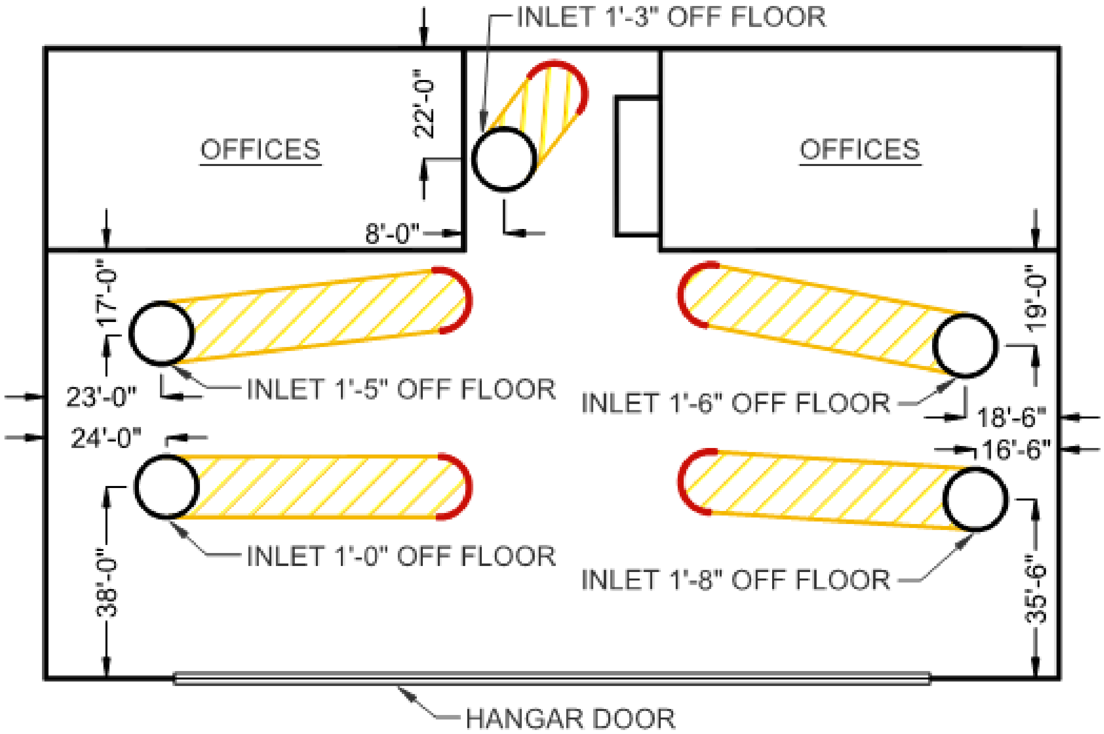


Figure 11. Overall Ductwork Configuration

3.5. Video Coverage and Foam Depth Monitoring

Eight GO-PRO cameras were installed in the hangar during each test. Four of the cameras where installed to provide wide angle views of the foam discharge and the filling process (i.e., to monitor and record foam depth as a function of time). Two cameras were aimed specifically at the inlet to the vertical ducts and the remaining two focused on the generators themselves.

To aid in assessing the foam depth as a function of time, five, depth indicators were installed in the hangar during each test. The depth indicators consisted of a 2 in. PVC vertical pipe stand with makings at one foot increments. Three depth indicators were installed equally spaced down the centerline of the hangar (i.e., the location of the fuselage when a plane is parked in the hangar), and the remaining two positioned at the wing tip locations. A close up of a depth indicator and there installed locations are shown if Figure 12.

Figure 12. Depth Indicator Locations

4. TEST TIMING AND PROCEDURES

Prior to the start of the test, the curtains along each boundary were sealed and all systems were verified to be operational. All personnel were then required to report to their respective positions. The video cameras were then started and the hangar was cleared of all personnel. Once all personnel were accounted for, the high expansion foam system was then activated. The system was activated from a pull station located just inside the south side access door to the hangar. The system conditions were monitored by an operator (Mr. Jim Devonshire) located in the high expansion foam pump room accompanied by maintenance personnel from the base. On completion of the test/discharge, the system was secured by the personnel located in the pump room on the south end of the hangar.

During the first discharge (baseline test without ductwork), the system was activated for approximately two minutes which resulted in an eight-foot foam depth throughout the hangar. During the second discharge (validation test with ductwork connected to the generators), the system was activated for approximately five minutes to verify that steady state conditions (i.e., foam depths) were achieved.

After each test, the hangar was secured and personnel were not allowed back into the space until the following day to begin cleanup. Cleanup and collection of the effluent was the responsibility of the base environmental subcontractor (SWS Environmental Services). Jensen Hughes personnel oversaw the effluent removal.

5. **RESULTS AND DISCUSSION**

The test program was conducted during the week of May 15th, 2017. The baseline test (Test 1) was conducted on Monday, May 15th and the validation test (Test 2) was conducted on Wednesday, May 17th. A description of each tests in provided in the following sections.

5.1. Baseline Test (Test 1)

The baseline test (Test 1) was witness by two base maintenance personnel (Daniel Andersen and Chuck Lanning) and the USAF sponsor (Raymond Hansen).

Prior to the test, the system was flushed with water to validate the operating status of the system. During the flushing of the system, several system issues (i.e., leaky rubber flange gaskets and clogged sensing lines (clogged with pipe dope)) were identified and repaired prior to the actual test. Additional base personnel assisted in repairing the system.

During the actual discharge test, the system was operated for approximately two minutes. The system was operated about 30 seconds longer than planned due to radio communication issues between the Test Director and system operator (i.e., the system operator had trouble hearing the Test Director over the noise made by the pump during operation). The slightly longer discharge time had no adverse effects on the test or hangar.

A series of photographs showing the filling of the hangar with foam (at 30 second increments) are provided as Figure 13. The resulting foam depth in the hangar at the end of the two-minute discharge was approximately 8 ft. As shown in the photographs, the foam initially piles-up in the center of the hangar directly below the generators and gradually flows to the hangar boundaries. During the discharge, there can be a 6-8 ft gradient between the highest and lowest part of the foam blanket. During the baseline test, the foam took approximately 90 seconds to reach the hangar boundaries.

It should be noted that while the figure shows ductwork running to three of the generators, the ductwork was not connected to the generator during the test (i.e., the ductwork terminated about 5 ft from the generator).

Time = 0:00 +	Time = 0:30
	
Time = 1:00	**Time = 1:30**
	
Time = 2:00	**Time = 5:00**
	

Figure 13. Test 1 Results/Filling Sequence

5.2. Validation Test (Test 2)

The validation test (Test 2) was conducted on Wednesday, May 17th. The test was witness by two base maintenance personnel (Daniel Andersen and Chuck Lanning) and the USAF sponsor (Raymond Hansen). The base fire department, led by Chief Mark Giuliano, also witnessed the test and conducted various search and rescue drills in the foam, after the test was complete. The videos and still photographs taken during these drills were provided to the Chief and are available on request.

During the validation test, the system was operated for approximately five minutes. The foam reached the duct inlets approximately three minutes into the discharge. By four minutes into the discharge, the foam being discharged by the generators had a very low expansion ration and was “soupy” in nature.

A series of photographs showing the initial filling of the hangar with foam (at 30 second increments) are provided as Figure 14.

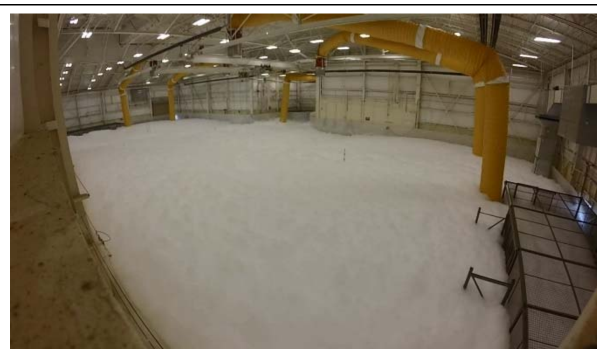
Time = 0:00 +	**Time = 0:30**
	
Time = 1:00	**Time = 1:30**
	
Time = 2:00	**Time = 6:00**
	

Figure 14. Test 2 Results/Filling Sequence

The friction loss associated with the airflow through the ductwork appears to have reduced the foam production rate of the generators/system resulting in a slower fill rate. A comparison showing the differences in fill levels, one minute into the system discharges is provided in Figure 15.

Baseline Test – 1:00	**Validation Test – 1:00**
	

Figure 15. Fill Rate Comparison – With and Without Ductwork

As shown in the Figure 15, and determined through an assessment of the fill depth indicators, the ductwork tended to reduce the foam production rate by about 25%. This is consistent with the results of the intermediate scale tests (i.e., the intermediate scale tests showed a 35% reduction in foam production rate). The foam produced by the system also appears to have a slightly lower expansion ratio also consistent with the results of the intermediate scale tests.

The foam didn’t completely cover the duct inlets until about three minutes into the test. As the foam approached the inlets, it was apparent that the foam was being ingested into the duct. Once the inlet was completely submersed in foam (between three to four minutes into the test), there was no indication that the foam was still being ingested (i.e., there was no foam movement anywhere near the inlet). The system remained activated for an additional two minutes for a total discharge time of five minutes. The resulting/final foam depth in the hangar was between 6-7 ft.

As the inlets became covered with foam, the expansion ratio of the foam being produced by the generators began to decrease. Over the course of the two-minute period after the duct inlets were covered with foam, the foam went from well expanded to virtually no expansion at all. A series of photographs showing the last four minutes of the discharge (at one minute increments) are provided as Figure 16.

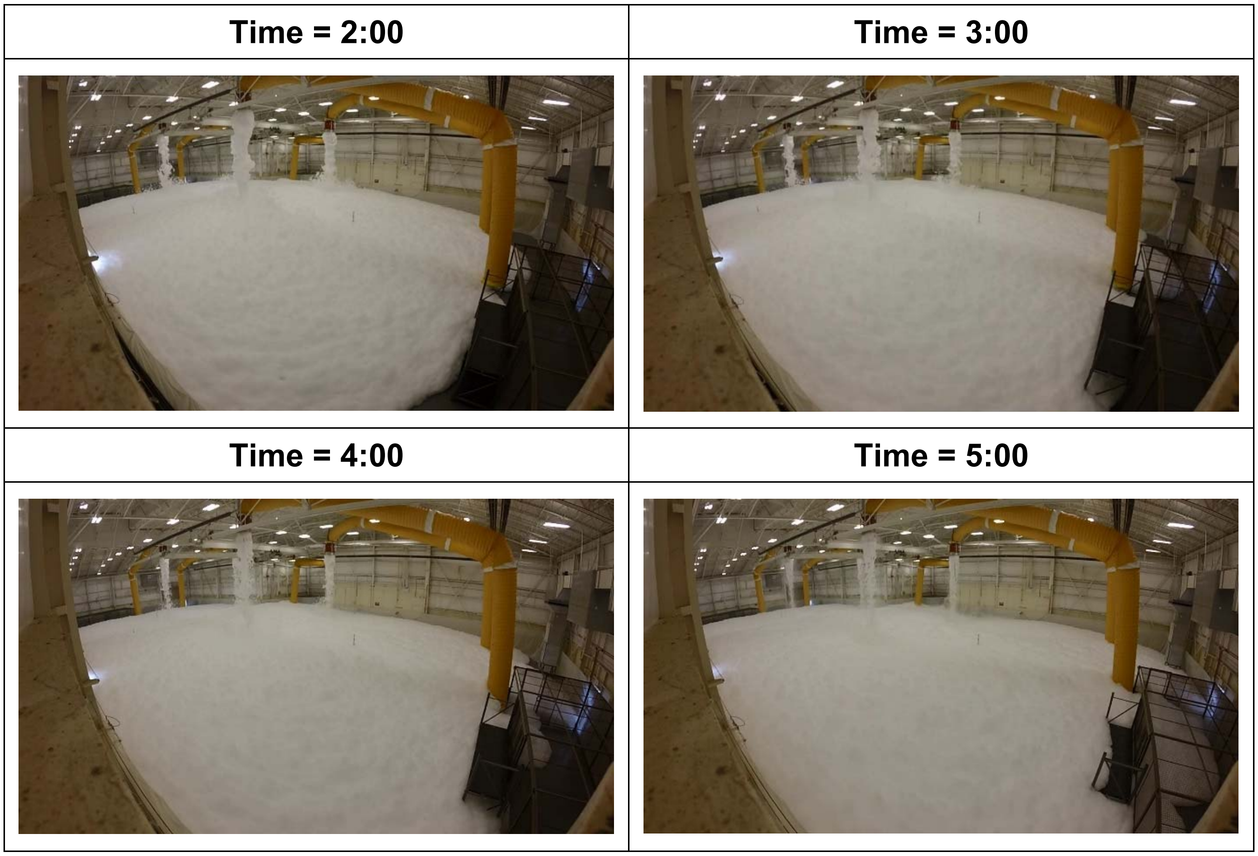


Figure 16. Reduction in Foam Expansion Ratio

Close-up photographs of the foam being discharged by the generators before and after the inlets were cover with foam are provided in Figure 17.

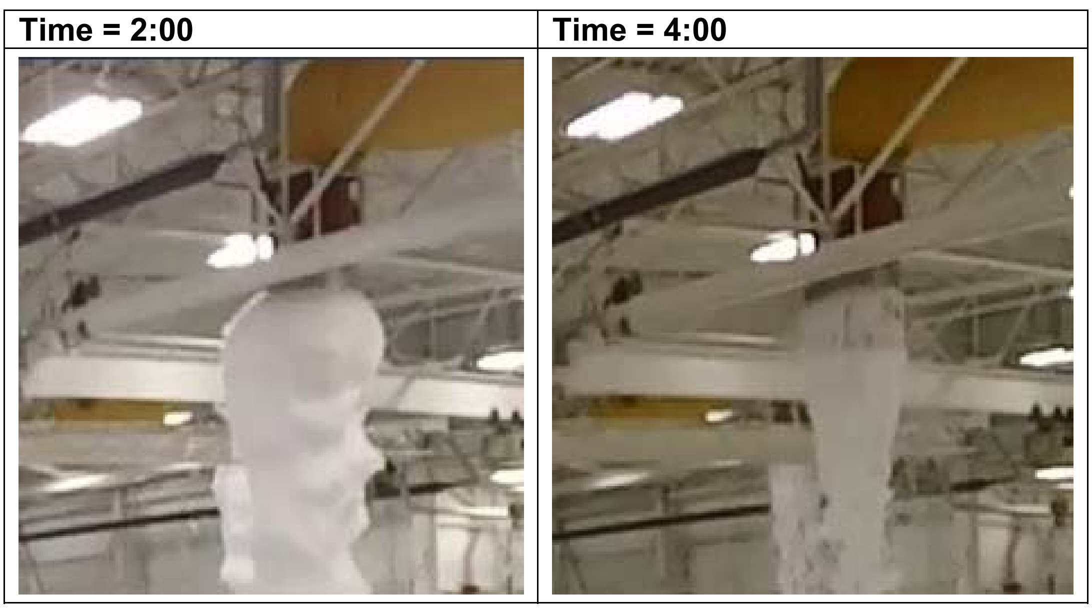


Figure 17. Expansion Ratio Comparison

5.3. Discussion

The original design concept was developed based on the assumption that the foam would be ingested into the ductwork and recirculated by the generator maintaining the foam at a constant depth throughout the hangar. During these test (and during the intermediate scale tests), the foam does not appear to be recirculated by generator but rather appears to clog the ductwork shutting off the air to the generator. Specifically, once the inlets of the duct are completely submersed in foam, there is no movement of the foam around/toward the inlet.

However, independent of the mechanism, the addition of the ductwork limited the depth of the foam during discharge to approximately 6 ft. throughout the hangar meeting the initial intent of the program.

With respect to friction loss through the ductwork, in both the intermediate and full-scale test programs, the ductwork was approximately the same diameter as in the generator inlet. If the longer fill times become an issue, slightly larger ductwork should be considered.

6. SUMMARY AND CONCLUSIONS

The USAF has developed a technique to reduce the consequences (i.e., collateral damage of aircraft electronics) of an inadvertent discharge of a high expansion foam system by controlling the maximum height/depth of the foam. Specifically, the inlet air to each high expansion foam generator would be drawn from the critical height above the deck/floor through ductwork. Once the foam reaches this critical height, the foam, in theory, would then be recirculated through the generator keeping the height of the foam relatively constant.

An intermediate scale test program was conducted to assess/validate the proposed concept on a reduced scale using a single high expansion foam generator in a warehouse configuration. The program was conducted to provide some baseline data on friction loss through the ductwork (i.e., reduced foam production due to the presence of the ductwork) and relation between the maximum fill height in the hangar and the duct inlet height. The intermediate scale test program was a logical first step in validating the concept and developing an understanding of the associated design parameters.

In all six intermediate scale tests conducted with the ductwork system, the foam generator stopped making foam shortly after the inlet to the ductwork was immersed in foam. The original USAF design concept was developed based on the assumption that the foam would be ingested into the ductwork and recirculated by the generator keeping the foam at a constant depth throughout the hangar. During these test, the foam was never recirculated by generator but rather appeared to clog the ductwork shutting off the air to the generator.

During the full-scale validation test, the foam also did not appear to be recirculated by generator but rather appears to clog the ductwork shutting off the air to the generator. Specifically, once the inlets of the duct were completely submersed in foam, there was no movement of foam around/toward the inlet and the expansion ratio of the foam being discharge by the generator was significantly reduced.

However, independent of the mechanism, the addition of the ductwork limited the depth of the foam during discharge to approximately 6 ft. throughout the hangar meeting the intent of the program.

The addition of the ductwork did reduce the foam production rate between 25-35% in both the intermediate and full-scale test programs. If the longer fill time (system degradation) becomes an issue, slightly larger ductwork should be considered.

With respect to the height of the duct inlet, since there is typically a 6 – 8 ft. gradient between the height of the foam under the generators and the perimeter of the space, the 16 in. elevation used during these tests is recommended for future installations.

7. REFERENCES

1. U.S. Air Force ETL 02-15, Requirements/Specification for Hangar Fire Protection Systems
2. Converting Hangar Foam Systems to Prevent Cockpit Damage -Intermediate Scale Testing, Jensen Hughes Report 1DAW15002.006 – 02, March 21, 2016
3. Chemguard, Water Powered High Expansion Foam Generators, Data Sheet #D10D03090, August, 2009
4. Duct Manufacturer’s Website, http://www.schauenburg.ca/Products/FlexibleDucting.aspx

FOAM SYSTEM INSPECTION/TEST/ MAINTENANCE REPORT

ISO 9001

1170 West Corporate Drive
Suite 201
Arlington, TX 76006 USA
(817) 633 – 3626
(817) 633 – 5884 Fax

Foam system equipment:	300-gallon capacity horizontal bladder tank, (1) 4 inch Ratio controller (1), 1 ½ inch Concentrate Control Valve, (1), 2.0% High-Expansion foam Concentrate. Chemguard High Expansion Foam Generator, (5).
Service performed:	Inspect system, check foam concentrate level and refill bladder tank after all testing.
Project:	Hangar 3029, Duke Field, FL.
Customer:	Jensen Hughes, Inc.
Service performed by:	Jim Devonshire.
Service date:	May 14 – 19, 2017.
System status:	**Off-Line (May 18, 2017).**
Pages to report:	Eight (8) + graph.
Personnel present:	Jerry Back – Jensen Hughes, Inc. Ray Hansen – USAF Personnel – Duke Field Personnel – Jensen Hughes, Inc. Jim Devonshire – BFEC

FOAM CONCENTRATE AND HARDWARE.

Foam concentrate type:	Chemguard C-2, 2% High Expansion Foam Concentrate
Foam concentrate percentage:	2%
Lot number – (for replacement):	C2701 (Manufactured 03/17) & C2603 (Manufactured 08/16)
Foam concentrate tank type:	300-gallon capacity Horizontal bladder tank (1)
Serial Number of tank(s):	10 – 8677
Material of Construction:	Carbon steel with Flexiliner bladder
Leakage from tank:	No
Comments:	N/A

2

FOAM EQUIPMENT ROOM.

Orderly:	Yes
Well illuminated:	Yes
Foam storage temperature properly maintained:	Yes
System modifications made since last inspection:	N/A

Foam system support equipment

Liquid level switches:	N/A
Foam concentrate strainers:	N/A
Gauges:	N/A
Power supplies:	N/A
Pump Controllers:	N/A
Control Panels:	N/A

Comments:

None.

FOAM CONCENTRATE PIPE & FITTINGS.

Mechanical damage:	None
External condition:	O.K.
Type of fittings:	Stainless steel, threaded/grooved.
Properly supported:	Yes

Correct type of pipe & fittings:	No – should be welded/flanged (not threaded)
Foam concentrate valves:	
Tagged:	No
Accessible:	Yes
Indicating Type:	Yes
Free turning:	Yes
Type of automatic valves:	Flanged-end water powered ball valve
Valve tested:	Yes
Method of operation:	Water pressure.
Valve sealed in correct position:	N.A.
Valves provided with tamper switch:	Yes, foam concentrate (only)

Comments:

None.

FOAM PROPORTIONING EQUIPMENT.

Tank capacity:	300 gallons.
Sight glass installed:	Yes
Bladder integrity test performed:	Yes
Foam concentrate from water drain valve:	No

Tank normally under pressure:	Yes
Relief valve installed:	Not required
Relief valve set pressure:	N/A

Comments:

None.

PROPORTIONING SYSTEM FLOW TESTING.

System flow accomplished by: Flow through system piping to hangar area.

Representative samples of foam solution mixed:

Sample percentage	Conductivity reading
1%	631
2%	850
3%	1031

Method of measurement: Conductivity with Ex-Stik II, EC500 Multi-Range Conductivity Meter.

Foam solution test results

Test No.	Prop.	Est. Flow	Device	Residual @ Riser	Conductivity	Percent	Time
JD	4"	~1,000 gpm	Foam Generators	N.R.	891	2.30	150 Secs
Duke	4"	~1,000 gpm	Foam Generators	N.R.	930	2.45	150 Secs

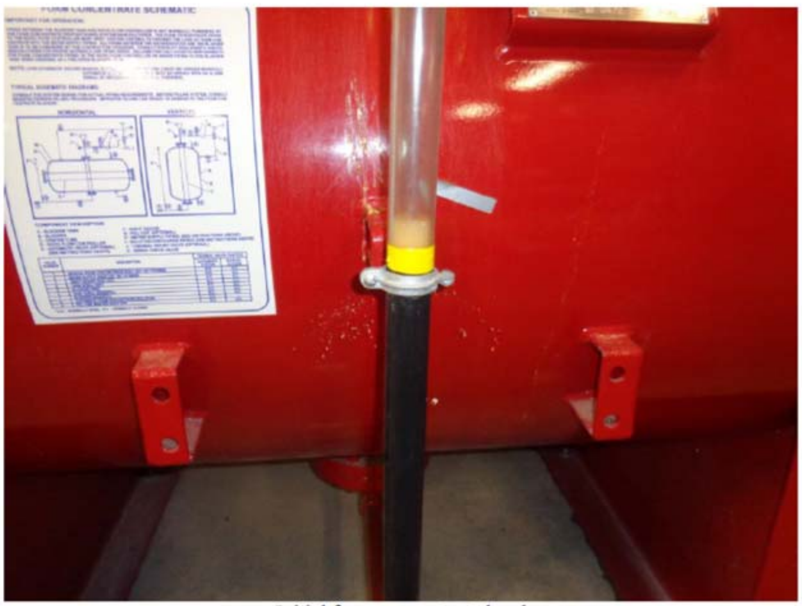
Foam concentrate tank refilled after testing: Yes. Approximately 55 gallons of foam concentrate were used for the preliminary test on May 15th 2017 and an additional 185 gallons were used for the testing on Wednesday May 17th 2017.

COMMENTS.

Upon arrival at site, the existing installed foam system was inspected and found to be in general conformance with typical high expansion foam systems.

The first task was to verify the foam concentrate level in the bladder tank.

Upon following OEM procedures for a foam concentrate level check, the bladder tank was isolated from the riser, the tank shell drain valve opened to drain water from the tank shell; the tank shell vent valve was opened, the bladder vent valve was opened and once all the water had drained from the tank shell, the bladder tank was found to be only half full.



Initial foam concentrate level

Base Maintenance Department provided a supply of foam concentrate and the bladder tank was topped-off to the appropriate level.

The "black" foam concentrate initially found in the sight glass appeared to be as a result of contact with the carbon steel pipe attached to the sight glass tube.

During the re-pressurisation of the bladder tank, one (1) of the gaskets in the foam concentrate line to the ratio controller failed. Subsequently, all four (4) gaskets in the foam concentrate line were replaced by the base Maintenance Department.

The system was activated for the initial water flow test, however, the water powered foam concentrate control valve failed to open. Upon investigation it was determined that this line was blocked with pipe debris that required thorough cleaning before testing could resume. Once the supply piping to the concentrate control valve was cleaned-out, the system functioned as expected.

THE SYSTEM WAS LEFT IN THE FOLLOWING CONDITION:

Off-Line Ready for Service. (May 18, 2017).

Respectfully Submitted,

James Devonshire

James Devonshire C.F.P.S.
Manager, Foam Business Development Group.